Oxidation of Mercury Across SCR Catalysts in Coal-Fired Power Plants Burning Low Rank Fuels

Quarterly Progress Report

Reporting Period Start Date   October 1, 2003
Reporting Period End Date: December 31, 2003

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January 31, 2004

DOE Cooperative Agreement No: DE- FC26-03NT41728

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Abstract

This is the fourth Quarterly Technical Report for DOE Cooperative Agreement No: DE-FC26-03NT41728. The objective of this program is to measure the oxidation of mercury in flue gas across SCR catalyst in a coal-fired power plant burning low rank fuels using a slipstream reactor containing multiple commercial catalysts in parallel. The Electric Power Research Institute (EPRI) and Argillon GmbH are providing co-funding for this program. This program contains multiple tasks and good progress is being made on all fronts. During this quarter, further analysis of the catalyst NO_x activity data, based on measurements in the slipstream reactor was carried out. Data were assembled from ten utility boilers at which Hg speciation measurements were made across SCR catalyst. These data provide information on units burning bituminous coals with a wide range of sulfur and chlorine contents.

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Executive Summary

This project received funding from the Department of Energy under Cooperative Agreement No: DE-FC26-03NT41728. The Electric Power Research Institute (EPRI) and Argillon GmbH are providing co-funding for this program. This project has a period of performance that started February 19, 2003 and continues through September 30, 2004.

Under a separate program (cooperative agreement DE-FC26-00NT40753), Reaction Engineering International (REI) has been funded by the Department of Energy to carry out research and development on NO_x control options for coal-fired utility boilers. The objective of one of the tasks in the NO_x-control program is to evaluate and model SCR catalyst deactivation. REI will be responsible for six-month testing of multiple commercial catalysts simultaneously in a power plant slipstream reactor. This multi-catalyst reactor provides an ideal test bed for advancing the state of knowledge regarding mercury oxidation by SCR catalysts, with a focus on low rank fuels.

In this program, REI is using the multi-catalyst slipstream reactor to determine oxidation of mercury across six separate SCR catalysts at AEP's Rockport Unit 1. During the six-month testing under the existing NO_x-control program, two week-long sampling campaigns for mercury speciation will be carried out: at the beginning of the six-month period and at an intermediate point. URS will conduct the one-week campaigns to measure gaseous mercury speciation at the inlet and at the outlet of each catalyst chamber.

The specific project tasks are:

- Task 1 Test Preparation
- Task 2 Test Plan
- Task 3 Field Measurements of Mercury Speciation
- Task 4 Data Analysis and Validation
- Task 5 Management and Reporting

During the last three months, our accomplishments included the following:

- Further analysis of the catalyst NO_x activity data, based on measurements in the slipstream reactor, suggests that catalysts C2, C3 and C4 showed a loss of activity from March to August, while catalyst C5 had about the same activity in August relative to March. It was difficult to make the comparison for catalyst C6 because of lack of data at similar process conditions.
- Data were assembled from ten utility boilers at which Hg speciation measurements were made across SCR catalyst. These data provide information on units burning bituminous coals with a wide range of sulfur and chlorine contents. There are data from only one unit burning a subbutiminous coal. If it exists and is available, more full-scale data for subbituminous coal should be obtained.

2

Experimental Methods

Within this section we present in order, brief discussions on the different tasks that are contained within this program. For simplicity, the discussion items are presented in the order of the Tasks as outlined in our original proposal.

Task 3 - Field Measurements of Mercury Speciation

Slipstream Reactor Description

The slipstream reactor designed to test the deactivation of SCR catalysts in the field is operational and collecting data at the AEP Rockport plant. The reactor contains six SCR catalysts in parallel and is designed to withdraw a flue gas sample at the exit of the economizer. The reactor contains five commercial catalysts, both plate and honeycomb type, and one blank ceramic monolith. The commercial honeycomb catalysts have approximately a 7 mm pitch. The blank monolith has a slightly smaller pitch of 6.4 mm. Details of the catalysts' physical properties are given in Table 1. The six catalysts, four monolith and two plate, are configured as shown in Figure 1.

Table 1. Catalyst Properties.

Chamber:	**1 (Blank)**	**2**	**3**	**4**	**5**	**6**
Catalyst type:	Monolith	Monolith	Plate	Plate	Monolith	Monolith
Chamber porosity:	58.7%	75.4%	83.4%	85.1%	70.0%	67.6%
Length of catalyst in chamber (inch):	24.4	21.6	43.0	39.5	19.3	19.8
Area per chamber (ft^2):	0.028	0.028	0.128	0.144	0.031	0.030
Number of sub-chambers:	4	4	1	1	4	4
Geometric surface area (ft^2/ft^3):	271.0	153.7	106.1	106.1	149.3	138.0
Volume of catalyst block (ft^3):	0.226	0.200	0.458	0.475	0.202	0.198

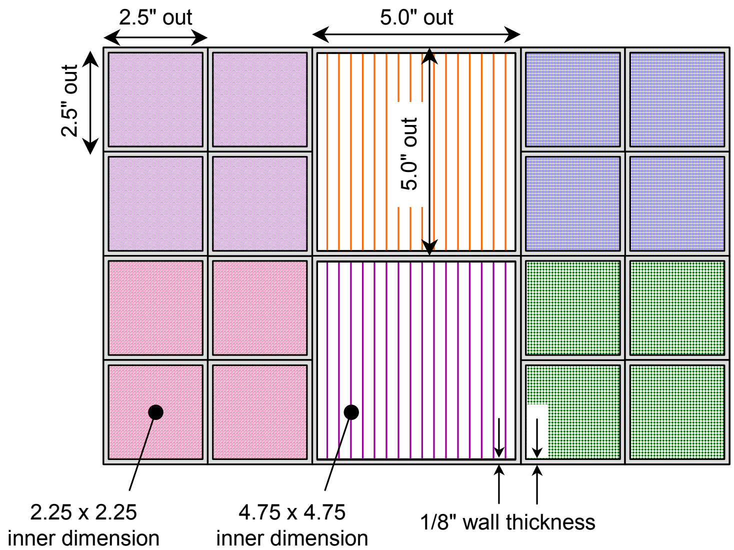

Figure 1. Arrangement of catalysts (plan view).

NO_x Reduction in Slipstream Reactor

In the previous quarterly report, the NOx data obtained during the second mercury test period were discussed. NO_x data were also obtained in late March and early April (approximately 750 hours of operating time on flue gas) and in late August at the conclusion of the second mercury sampling campaign (approximately 2200 hours of operating time on flue gas). These data will be analyzed to look at the effects of operating conditions and catalyst age on NO_x reduction. These data have also been reported under REI's NO_x control program (cooperative agreement DE-FC26-00NT40753); analysis of the data was carried out jointly between the two programs.

Appendix A contains the NO_x data from the blank catalyst as well as catalysts C2 through C6. The NO_x concentration at the inlet is calculated at 5% O_2. The inlet concentration has been interpolated based on measurements of the inlet concentration made before and after the measurement of the NO_x concentration at the outlet of each chamber. The ammonia concentration was calculated at 5% O_2, based on the total flow measured in the slipstream reactor and the set point of the ammonia mass flow controller. The NH_3/NO ratio is calculated from the ammonia concentration divided by the estimated inlet NO_x concentration. The average catalyst chamber temperature is calculated from the average of the temperature before the catalyst and at the exit of the catalyst chamber. The space velocity is calculated at 32 F (0 C).

There were differences in the temperatures, space velocities and ratios of NH_3/NO between the March/April data and the August data. In order to compare the NO_x reduction, the effects of these parameters must first be characterized.

The March/April data were taken at excess ammonia (NH_3/NO ~ 1.2-1.6) in order to remove any effects of ammonia concentration. The temperatures were in the range of 620-650 F. The main factor that affected the NO_x reduction was the space velocity. Figure 2 shows the NO_x reduction as a function of space velocity for all five catalysts. The NO_x reduction for catalysts C2, C3 and C4 appeared to follow a single curve with space velocity. Catalysts C5 and C6 had different levels of NO_x reduction from the other three; the slopes were about the same, but the intercepts were different.

Some of the August NO_x data were taken during the mercury testing; at this time the ammonia to NO ratio was varied. As the NH_3/NO ratio dropped below 0.95, the NO_x conversion began to fall off. This is seen in Figure 3, which shows the NO_x reduction as a function of NH_3/NO ratio at fixed temperatures and space velocities.

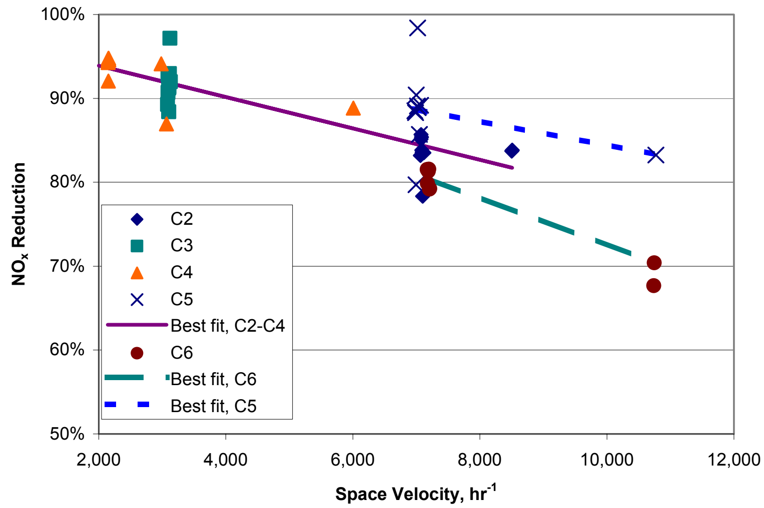

Figure 2. NO_x reduction as a function of space velocity for commercial catalysts from March/April for excess ammonia and catalyst temperatures in the range of 620-650 F.

The effect of temperature on NO_x reduction can also be seen in the August data. Figure 4 shows the NO_x reduction as a function of temperature at a fixed space velocity, all for NH_3/NO > 0.95. Since the March/April data were obtained at different temperatures and space velocities than the August data, the August data were corrected for temperature by using the curvefits shown in Figure 4 and Table 2. Such curvefits should not be used for large temperature corrections; however, the upper end of the range of temperatures in March/April data is generally close (0 to 8 F) to the lower end of the August temperature range for catalysts C2 through C5. There is a 20 F gap in temperature ranges for C6; therefore extrapolation of the C6 data is suspect.

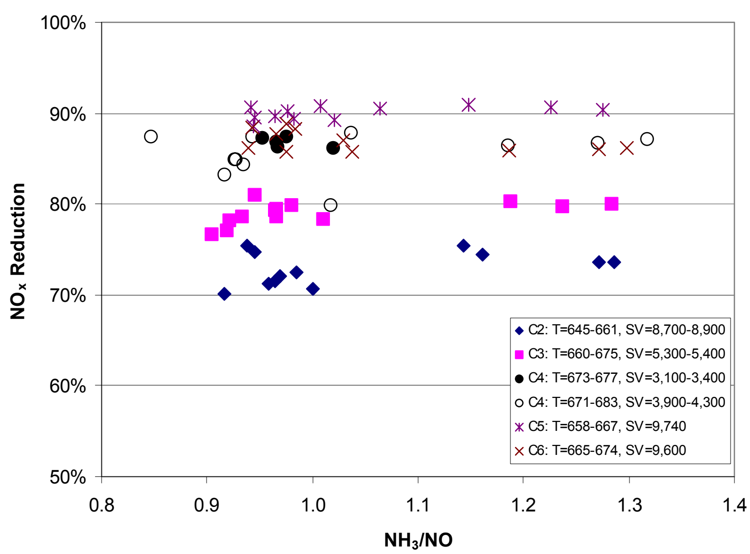

Figure 3. NO_x reduction as a function of NH_3/NO ratio for commercial catalysts from August; temperatures (in degrees F) and space velocities (in hr^{-1}) as indicated on legend.

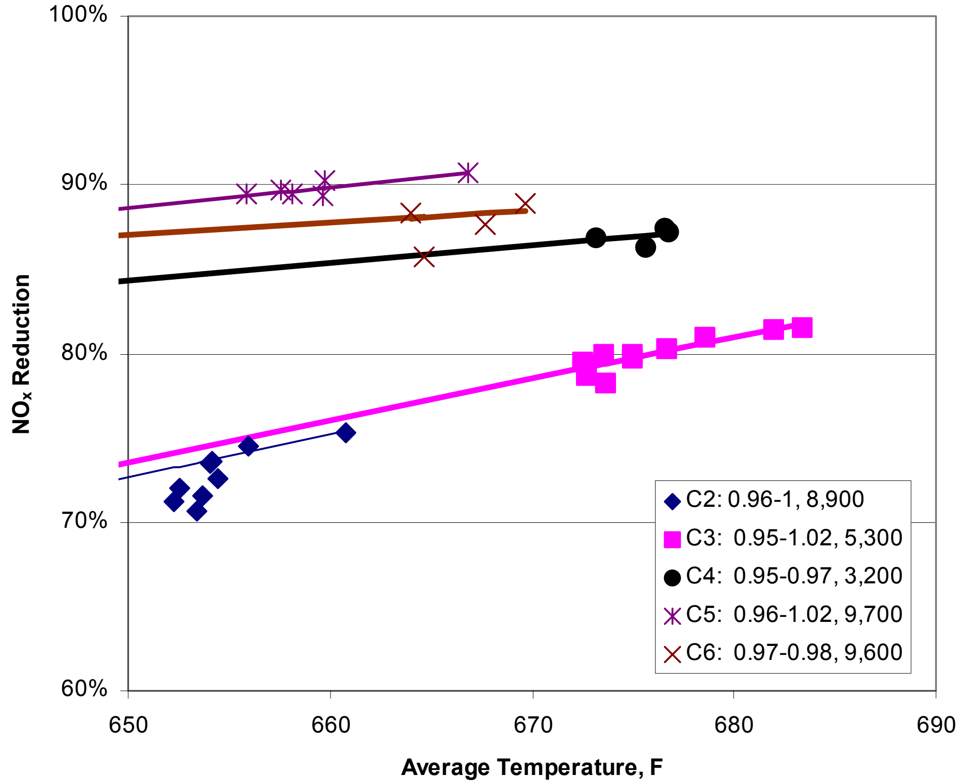

Figure 4. NO_x reduction as a function of temperature for commercial catalysts from August; NH_3/NO ratios and space velocities (in hr^{-1}) as indicated on legend.

Table 2. Relationship between NO_x reduction and temperature from August test data.

Catalyst	C2	C3	C4	C5	C6
Space velocity, hr^{-1}	8,900	5,300	3,200	9,700	9,600
NH_3/NO	1.14-1.29	0.95-1.02	0.97-0.97	0.96-1.02	0.97-0.98
Temperature range, F	653-661	674-683	676-685	660-669	670-675
r^2	0.95	0.80	0.38	0.68	0.12
Intercept	-97.2	-87.1	16.7	9.2	39.4
Slope	0.261	0.247	0.104	0.122	0.073

Figure 5 compares the March/April NO_x data with the August NO_x data. The August data show the range of NO_x reductions that correspond to the temperature range of the data of the March/April data. Catalysts C2, C3 and C4 appear to have lower NOx reduction in August as compared to March/April. Catalyst C5 has about the same NOx reduction. Catalyst C6 appears to have higher NOx reduction in August as compared to March/April; however, extrapolating the C6 NO_x reduction to the range of temperatures of the March/April tests may produce larger errors than for the other catalysts, as discussed previously.

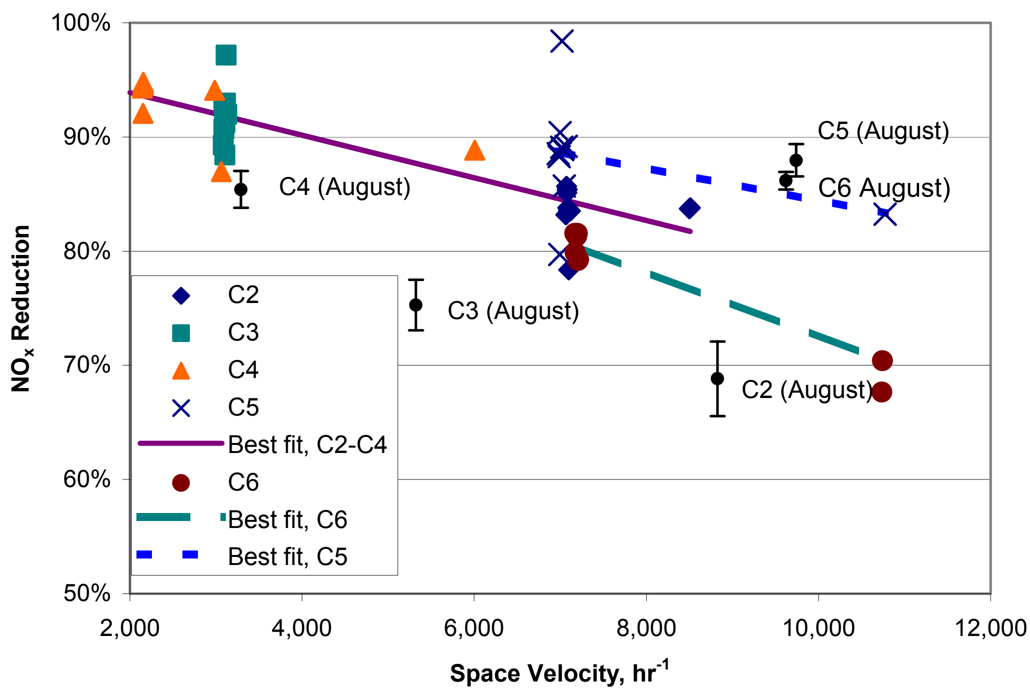

Figure 5. NO_x reduction as a function of space velocity for commercial catalysts from March/April for excess ammonia and catalyst temperatures in the range of 620-650 F compared with August data (extrapolated to the appropriate temperature range_.

Task 4 - Data Analysis and Validation

Data have been collected from measurements of mercury speciation across SCRs in ten full-scale power plants. Some of these plants were tested under the DOE/EPRI/EPA program; other plants represent data that REI has obtained directly from utilities. The data collected is summarized in Table 3.

Table 3. Full-Scale SCR data sets.

Year	2002	2002	2002
Reference	B3	B3	B3
Scale	full scale	full scale	full scale
Boiler Capacity, MW	Run 1,3,5,7,9: 900 MWe, Run 2,4,6,8,10-13: 1300 MWe	Run 1,3,5,7,9: 900 MWe, Run 2,4,6,8,10-13: 1300 MWe	Run 1,3,5,7,9: 900 MWe, Run 2,4,6,8,10-13: 1300 MWe
Boiler Type	wall- fired	wall- fired	wall- fired
NOx Control	SCR	SCR	SCR
SO2 Control			
Particulate Control	ESP	ESP	ESP
FGC: Other			
SCR Catalyst Type	plate	plate	plate
SCR Mfr			
SCR Space velocity, 1/hr			
SCR Installed (year)	2002	2002	2002
SCR Catalyst Age			
SCR Notes	Run 1,2,13: SCR in bypass	Run 3,4,12: SCR in service No NH3	Run 5,6,7-11: SCR in Service with NH3
Coal Rank	bituminous coal	bituminous coal	bituminous coal
Coal Origin	Run 1-2/ 13	Run 3-4/ 12	Run 5-6/ 7-11
Coal - ultimate [%S, AR]	0.77/ .70	0.7/ 0.70	0.8/ 0.70
Coal, Hg ug/g (dry)	0.13/ .095	0.11/ .095	0.11/ .076
Coal, Cl ug/g (dry)	800/ 1152	800/ 1152	800/ 1522
Ash -Bottom	No	No	No
Ash - Economizer	Hg data/ No	Hg data/ No	Hg data/ No
Ash - Fly Ash	Hg data/ Hg data, LOI	Hg data/ Hg data, LOI	Hg data/ Hg data, LOI
FG Location 1 - Economizer Out	Ave Run 1,2/ 7-11	Ave Run 3,4/ 12	Ave Run 5,6/ 13
Data	T, Hg species/ Hg species	T, Hg species/ Hg species	T, Hg species/ Hg species
FG Location 2 - SCR Out	Ave Run 1,2, 13	Ave Run 3,4, 12	Ave Run 5,6,7-11
Data	Hg species	Hg species	Hg species
FG Location 3 - Air Heater Out			
Data	No	No	No
FG Location 4 - ESP Out			
Data	No	No	No
FG Location 5 - FGD Out			
Data	No	No	No
FG Location 6 - Stack Out	Ave Run 1,2, 13	Ave Run 3,4, 12	Ave Run 5,6,7-11
Data	Hg species	Hg species	Hg species

Table 3 [continued]. Full-Scale SCR data sets.

Year	2003	2002
Reference	B4	B5
Scale	full scale	full scale
Boiler Capacity, MW	650	Run 3,6: 900 MWe, Run 1,2,4,5,7: 1300 MWe
Boiler Type	wall-fired	
NOx Control	SCR	SCR
SO2 Control		
Particulate Control	Hot-side ESP	ESP
FGC: Other		
SCR Catalyst Type		plate
SCR Mfr		
SCR Space velocity, 1/hr		
SCR Installed (year)		
SCR Catalyst Age		
SCR Notes	two identical reactors	Run 5: SCR in bypass
Coal Rank	eastern bituminous	No
Coal Origin		
Coal - ultimate [%S, AR]	0.91	0.69
Coal, Hg ug/g (dry)	0.08	0.06
Coal, Cl ug/g (dry)	1665	1032
Ash -Bottom	Hg data	No
Ash - Economizer	No	No
Ash - Fly Ash	Hg data, LOI	Hg data, LOI
FG Location 1 - Economizer Out		Run 5: SCR in bypass
Data	T,Hg species	T, Hg species
FG Location 2 - SCR Out		Run 5: SCR in bypass
Data	T,Hg species	T, Hg species
FG Location 3 - Air Heater Out		
Data	No	No
FG Location 4 - ESP Out		
Data	No	No
FG Location 5 - FGD Out		
Data	No	No
FG Location 6 - Stack Out		Run 5: SCR in bypass
Data	Hg species	Hg species

Table 3 [continued]. Full-Scale SCR data sets.

Year	2002	2002	2001
Reference	B5	B5	S1
Scale	full scale	full scale	full-scale
Boiler Capacity, MW	Run 3,6: 900 MWe, Run 1,2,4,5,7: 1300 MWe	Run 3,6: 900 MWe, Run 1,2,4,5,7: 1300 MWe	600 MW
Boiler Type			cyclone
NOx Control	SCR	SCR	SCR
SO2 Control			Low sulfur fuel
Particulate Control	ESP	ESP	ESP
FGC: Other			
SCR Catalyst Type	plate	plate	honey comb
SCR Mfr			Cormetech
SCR Space velocity, 1/hr			1800
SCR Installed (year)			
SCR Catalyst Age			8000 hr
SCR Notes	Run 4: SCR in service No NH3	Run 1-3,6-7: SCR in Service with NH3	Normal Operation/ NH3 turned off/ Bypassed
Coal Rank	No	No	PRB subbituminous
Coal Origin			
Coal - ultimate [%S, AR]	0.69	0.68	
Coal, Hg ug/g (dry)	0.06	0.06	0.07
Coal, Cl ug/g (dry)	1032	1080	
Ash -Bottom	No	No	No
Ash - Economizer	No	No	No
Ash - Fly Ash	Hg data, LOI	Hg data, LOI	Hg data
FG Location 1 - Economizer Out	Run 4: SCR in service No NH3	Run 1-3,6-7: SCR in Service with NH3	SCR IN: Note NOx Data in units (ppmvd)
Data	T, Hg species	T, Hg species	T, dust, major gas, NOx, Hg species
FG Location 2 - SCR Out	Run 4: SCR in service No NH3	Run 1-3,6-7: SCR in Service with NH3	SCR OUT: Note NOx Data in units (ppmvd)
Data	Hg species	Hg species	T, dust, major gas, NOx, Hg species
FG Location 3 - Air Heater Out			ESP In
Data	No	No	T
FG Location 4 - ESP Out			ESP Out
Data	No	No	No
FG Location 5 - FGD Out			
Data	No	No	No
FG Location 6 - Stack Out	Run 4: SCR in service No NH3	Run 1-3,6-7: SCR in Service with NH3	
Data	Hg species	Hg species	T, major gas, Hg species

Table 3 [continued]. Full-Scale SCR data sets.

Year	2001	2002	2001
Reference	S2	S2	S3
Scale	full-scale	full-scale	full-scale
Boiler Capacity, MW	1300	1360MW	750
Boiler Type	wall-fired	wall-fired	tangential-fired
NOx Control	Low NOx burners, SCR	low NOx burner and SCR	Low NOx burners with overfire, SCR
SO2 Control	Wet Scrubber	magnesium-enhanced lime FGD	None
Particulate Control	ESP	ESP	ESP
FGC: Other		alkali injected	
SCR Catalyst Type	plate	plate	honey comb
SCR Mfr	Siemens/Westinghouse	Siemens/Westinghouse	KWH
SCR Space velocity, 1/hr	2125	2125	3930
SCR Installed (year)			
SCR Catalyst Age	2500 hr		3600 hr
SCR Notes	Normal Operation/ Bypassed		Normal Operation/ NH3 turned off/ Bypassed
Coal Rank	bituminous	bituminous	bituminous
Coal Origin	Ohio	Ohio	Pennsylvania
Coal - ultimate [%S, AR]		3.85	
Coal, Hg ug/g (dry)	0.17	0.12	0.40
Coal, Cl ug/g (dry)	573-1910	633	721-1420
Ash -Bottom	No	No	No
Ash - Economizer			
Ash - Fly Ash	No	Hg, LOI	
FG Location 1 - Economizer Out	SCR In	SCR In	SCR In
Data	Hg species	dust, major gas, Hg species	Hg species
FG Location 2 - SCR Out	SCR Out	SCR Out	SCR Out
Data	Hg species	dust, major gas, Hg species, NH3, SO3	Hg species
FG Location 3 - Air Heater Out	ESP In	ESP IN	ESP In
Data	Hg species	dust, major gas, Hg species	Hg species
FG Location 4 - ESP Out	ESP Out	ESP OUT	
Data	Hg species	dust, major gas, Hg species, NH3	No
FG Location 5 - FGD Out			
Data	No	No	No
FG Location 6 - Stack Out	Stack	STACK	Stack
Data	Hg species	dust, major gas, Hg species	Hg species

Table 3 [continued]. Full-Scale SCR data sets.

Year	2001	2002	2002
Reference	S4 (2001)	S4 (2002)	S4 (2002)
Scale	full-scale	full-scale	full-scale
Boiler Capacity, MW	650	704 MW gross	704 MW gross
Boiler Type	cyclone	cyclone	cyclone
NOx Control	SCR	SCR and overfire air	SCR and overfire air
SO2 Control	Lime venturi scrubber	particulate/SO2 venturi/spray tower scrubber	particulate/SO2 venturi/spray tower scrubber
Particulate Control	Lime venturi scrubber	particulate/SO2 venturi/spray tower scrubber	particulate/SO2 venturi/spray tower scrubber
FGC: Other			
SCR Catalyst Type	honeycomb	vanadium/titanium honeycomb	vanadium/titanium honeycomb
SCR Mfr	Cormetech	Cormetech	Cormetech
SCR Space velocity, 1/hr	2275	2275	2275
SCR Installed (year)			
SCR Catalyst Age	3600 hr	2 ozone seasons	2 ozone seasons
SCR Notes	Normal Operation/ NH3 turned off/ Bypassed	SCR in service 9/11-9/13/02	SCR without service 10/16-10-17/02
Coal Rank	bituminous coal	bituminous	bituminous
Coal Origin	Kentucky	Kentucky	Kentucky
Coal - ultimate [%S, AR]		2.80	2.57
Coal, Hg ug/g (dry)	0.13	0.17	0.16
Coal, Cl ug/g (dry)	357-1160	250	269
Ash -Bottom	No	No	No
Ash - Economizer			
Ash - Fly Ash			
FG Location 1 - Economizer Out **Data**	SCR In Hg species	SCR IN: Run 1 /2 /3 dust, major gas, SO3, Hg species	dust, major gas, Hg species
FG Location 2 - SCR Out **Data**	SCR Out Hg speceis	SCR Out:Run 1/ 2/ 3 dust, major gas, SO3, NH3 Hg species	dust, major gas, Hg species
FG Location 3 - Air Heater Out **Data**	AH Out Hg speceis	AH Out: dust, major gas, Hg species	dust, major gas, Hg species
FG Location 4 - ESP Out **Data**	ESP Out No	No	No
FG Location 5 - FGD Out **Data**	No	No	No
FG Location 6 - Stack Out **Data**	Stack Hg speceis	Stack major gas, Hg species	Stack major gas, Hg species

Table 3 [continued]. Full-Scale SCR data sets.

Year	2002	2002	2002
Reference	S5	S6 (Unit 1)	S6 (Unit 2)
Scale	full-scale	full-scale	
Boiler Capacity, MW	684	700 MW	900 MW
Boiler Type	wall-fired	tangential-fired	tangential-fired
NOx Control	SCR,one unit, LNBs on both	SCR in bypass, LNBs	Low-NOx burners, SCR
SO2 Control	magnesium enhanced lime FGD	Low-sulfur compliance coal	Low-sulfur compliance coal
Particulate Control	ESP		
FGC: Other			
SCR Catalyst Type	plate	honeycomb	honeycomb
SCR Mfr	Halder-Topsoe	Cormetech	Cormetech
SCR Space velocity, 1/hr	3700	3800	3800
SCR Installed (year)			
SCR Catalyst Age	3 months	2 ozone seasons	2 ozone seasons
SCR Notes	2 sister units tested- 1 unit with SCR and 1 unit without SCR	In between the two ozone seasons, one layer changed	In between the two ozone seasons, one layer changed
Coal Rank	bituminous	eastern bituminous	eastern bituminous
Coal Origin	West Virginia	KY and WV	KY and WV
Coal - ultimate [%S, AR]	3.63	0.80	1.10
Coal, Hg ug/g (dry)	0.14	0.05	0.07
Coal, Cl ug/g (dry)	470	1,520	1,320
Ash -Bottom	No	No	No
Ash - Economizer			No
Ash - Fly Ash	Hg, LOI	Hg. LOI	Hopper: Hg, LOI
FG Location 1 - Economizer Out	SCR Inlet: Data for Unit with SCR/ Data for Unit without SCR		
Data	dust, major gas, SO3, Hg species	dust, major gas, Hg species	dust, major gas, SO3, Hg species
FG Location 2 - SCR Out	SCR OUT: Data for Unit with an SCR	SCR OUT	
Data	dust, major gas, NH3, Hg species	dust, major gas, SO3, NH3, Hg species	dust, major gas, SO3, NH3 Hg species
FG Location 3 - Air Heater Out	ESP IN: Data for Unit with SCR/ Data for Unit without SCR	ESP In	
Data	dust, major gas, SO3, Hg species	dust, major gas, SO3, Hg species	dust, major gas, SO3, Hg species
FG Location 4 - ESP Out	ESP OUT: Data for Unit with SCR/ Data for Unit without SCR		
Data	dust, major gas, Hg species	No	dust, major gas, Hg species
FG Location 5 - FGD Out			
Data	No	No	No
FG Location 6 - Stack Out	STACK: Data for Unit with SCR/ Data for Unit w/o SCR	Stack	Stack
Data	dust, major gas, Hg species	dust, major gas, Hg species	dust, major gas, Hg species

Results and Discussion

Task 3 - Field Measurements of Mercury Speciation

For catalysts C2 and C3, the NO_x activity in August (relative to the March/April data) was 85%. For catalyst C4, the activity was 93%. Catalyst C5 had an activity of about 100% in August relative to March. It is difficult to make any conclusion about catalyst C6.

The change in mercury oxidation from March to August is shown in Figure 6. Catalysts C3 (plate) and C5 (monolith) showed similar mercury oxidation between March/April and August. Catalysts C2 and C6 (monolith) and catalyst C4 (plate) showed less oxidation in August as compared to March/April. The change in mercury oxidation does not necessarily correlate with the change in NO_x activity. Catalyst C5 had the same level of NO_x reduction and mercury oxidation in March as in August. However, Catalyst C3 had lower NO_x reduction in August, but about the same level of mercury oxidation. Catalysts C2 and C4 showed less mercury oxidation in August than in March and also less NO_x reduction.

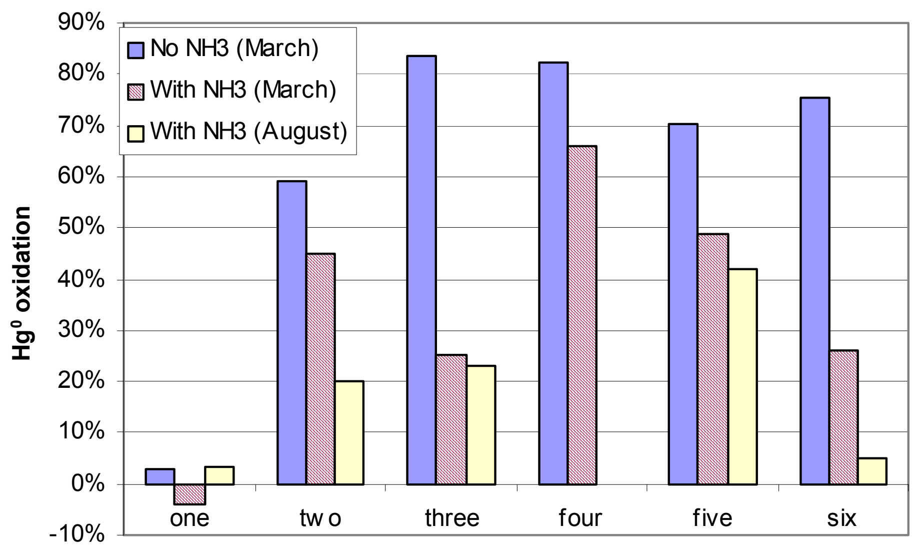

Figure 6. Mercury oxidation with and without ammonia estimate at 2,500 hr^{-1}; March/April test series: NH_3/NO=1.2-2.0; August test series: NH_3/NO=0.9-1.2.

Task 4 - Data Analysis and Validation

Data have been collected from measurements of mercury speciation across SCRs in ten full-scale power plants. Some of these plants were tested under the DOE/EPRI/EPA program; other plants represent data that REI has obtained directly from utilities.

Almost all the boilers, except one, fired eastern bituminous coals with a range of sulfur from 0.7 wt% to 3.8 wt%; chlorine contents ranged from 250 to 16,00 μg/g (dry basis). Most of the boilers were wall-fired; two were cyclones and three were tangentially fired. Measurements bypassing the SCR were made at six units. Measurements through the SCR with no ammonia were made at six units. At two units, the effect of load on Hg oxidation across the SCR was studied. At three of the units, measurements were made at two different times: two about a year apart and one six months apart. DOE sites S2 through S6 are missing information on the temperature of the SCR. The datasets from the non-DOE sites, although they contain temperature information, do not have any information on the space velocity of the catalyst. REI will follow up on these sites to see if more data can be obtained.

Task 5 - Management and Reporting

Results from portions of this research program have been reported to industry through technical presentations at conferences. One paper will be presented in the next quarter at the Electric Power Conference, Baltimore, Maryland, March 30-April 1, 2004:

- Constance Senior and Temi Linjewile, "Understanding Oxidation of Mercury Across SCR Catalysts in Power Plants Burning Low Rank Coals."

Another paper has been accepted for presentation at the Coal Utilization & Fuel Systems Conference in Clearwater, Florida, April 18-22, 2004:

- Constance Senior and Temi Linjewile, "Oxidation Of Mercury Across SCR Catalysts In Coal-Fired Power Plants."

Conclusions

Good progress has been made on several fronts during the last three months. In particular:

Further analysis of the catalyst NO_x activity data, based on measurements in the slipstream reactor, suggests that catalysts C2, C3 and C4 showed a loss of activity from March to August, while catalyst C5 had about the same activity in August relative to March. It was difficult to make the comparison for catalyst C6 because of lack of data at similar process conditions. The change in mercury oxidation from March to August did not necessarily correlate with the change in NO_x activity.

Data were assembled from ten utility boilers at which Hg speciation measurements were made across SCR catalyst. These provide data on units burning bituminous coals with a wide range of sulfur and chlorine contents. There are data from only one unit burning a subbutiminous coal. If they are available, more full-scale datasets for subbituminous coal should be obtained.

Plans for Next Quarter

- Analysis of the full-scale SCR data will begin next quarter.

Appendix A

Catalyst NO_x Data from Slipstream Reactor

The NO_x concentration at the inlet is calculated at 5% O_2. The inlet concentration has been interpolated based on measurements of the inlet concentration made before and after the measurement of the NO_x concentration at the outlet of each chamber. The ammonia concentration was calculated at 5% O_2, based on the total flow measured in the slipstream reactor and the set point of the ammonia mass flow controller. The NH_3/NO ratio is calculated from the ammonia concentration divided by the estimated inlet NO_x concentration. The average catalyst chamber temperature is calculated from the average of the temperature before the catalyst and at the exit of the catalyst chamber. The space velocity is calculated at 32 F (0 C).

Table A.1. NO_x data for catalyst C1 (blank monolith).

Chamber	Date	Inlet NO_x ppm (est)	NO_x reduc.	T before cat, F	NH_3/NO	Avg T catal, F	SV, hr^{-1}
one	3/26/03	329	6.1%	655	1.40	625	6,279
one	3/27/03	318	3.1%	662	1.35	634	6,283
one	8/11/03	334.5	6.1%	617	1.02	555	2,745
one	8/12/03	332.7	-0.3%	678	1.05	602	1,406
one	8/13/03	318.9	3.1%	617	0.94	553	1,803
one	8/21/03	392.5	-4.8%	696	0.88	654	4,050
one	8/21/03	383.3	1.8%	698	1.00	655	4,126
one	8/21/03	370.7	5.7%	691	1.23	647	4,225
one	8/21/03	373.4	12.8%	691	1.25	646	4,242

Table A.2. NO_x data for catalyst C2 (monolith).

Chamber	Date	Inlet NO_x ppm (est)	NO_x reduc.	T before cat, F	NH_3/NO	Avg T catal, F	SV, hr^{-1}
two	3/26/03	329.4	83.2%	657	1.43	627	7064
two	3/27/03	323.8	83.8%	662	1.43	628	7,087
two	3/27/03	335.9	85.4%	662	1.32	629	7,080
two	3/27/03	311.8	85.7%	655	1.32	623	7,073
two	3/27/03	308.5	83.5%	660	1.40	630	7,119
two	3/27/03	328.6	85.1%	658	1.29	628	7,076
two	3/27/03	239.6	78.4%	668	1.62	649	7,099
two	3/27/03	317.0	83.6%	667	1.26	648	7,093
two	4/5/03	301.4	83.8%	685	1.27	648	8510
two	4/5/03	301.4	83.7%	685	1.27	646	8501
two	8/11/03	334.5	71.4%	617	1.02	554	5,687
two	8/12/03	331.7	76.7%	644	1.20	570	3,568
two	8/13/03	318.9	62.2%	611	0.93	553	4,841
two	8/15/03	331.4	70.7%	612	1.23	543	5,125
two	8/21/03	383.6	74.8%	694	0.94	658	8,682
two	8/21/03	391.2	75.4%	698	0.94	661	8,654
two	8/21/03	382.7	75.4%	698	1.14	661	8,641
two	8/21/03	378.1	74.5%	692	1.16	656	8,696
two	8/21/03	371.1	73.5%	691	1.29	654	8,756
two	8/21/03	373.4	73.6%	691	1.27	654	8,751
two	8/22/03	361.6	72.2%	674	0.94	636	8,656
two	8/22/03	350.5	70.9%	678	0.92	641	8,800
two	8/22/03	337.5	69.2%	676	0.89	640	8,859
two	8/22/03	344.9	70.1%	683	0.92	645	8,967
two	8/22/03	365.7	72.0%	690	0.97	653	8,963
two	8/22/03	364.2	71.5%	690	0.96	654	8,973
two	8/22/03	345.5	70.6%	689	1.00	653	8,940
two	8/22/03	362.3	72.5%	690	0.98	654	8,837
two	8/22/03	351.9	71.2%	688	0.96	652	8,878

Table A.3. NO_x data for catalyst C3 (plate).

Chamber	Date	Inlet NO_x ppm (est)	NO_x reduc.	T before cat, F	NH_3/NO	Avg T catal, F	SV, hr^{-1}
three	3/26/03	311.3	93.0%	658	1.48	646	3113
three	3/27/03	324.0	92.8%	661	1.41	648	3,092
three	3/27/03	329.9	91.4%	665	1.21	652	3,105
three	3/27/03	309.4	91.2%	653	1.34	641	3,103
three	3/27/03	319.1	90.7%	659	1.34	649	3,092
three	3/27/03	327.4	92.0%	656	1.29	646	3,127
three	3/27/03	319.2	92.0%	661	1.52	651	3,101
three	3/27/03	318.7	89.3%	667	1.27	662	3,085
three	3/27/03	316.7	88.4%	668	1.27	663	3,103
three	4/5/03	301.4	97.2%	685	1.27	666	3120
three	8/16/03	349.1	56.8%	599	3.44	573	1,115
three	8/12/03	331.7	71.5%	678	0.97	652	2,583
three	8/13/03	318.9	64.7%	610	0.92	591	2,587
three	8/11/03	334.5	74.5%	619	1.01	600	2,599
three	8/16/03	349.1	84.2%	645	1.06	631	3,715
three	8/22/03	351.4	78.7%	688	0.97	673	5,251
three	8/22/03	363.3	79.9%	689	0.98	674	5,267
three	8/21/03	390.0	81.6%	700	1.02	683	5,293
three	8/21/03	382.0	81.5%	698	1.17	682	5,298
three	8/21/03	384.1	81.0%	695	0.95	679	5,322
three	8/21/03	377.0	80.3%	693	1.19	677	5,325
three	8/22/03	343.9	78.3%	690	1.01	674	5,330
three	8/21/03	371.4	80.0%	692	1.28	675	5,339
three	8/21/03	373.4	79.7%	692	1.24	675	5,345
three	8/22/03	365.9	79.3%	690	0.96	673	5,373
three	8/22/03	336.2	76.7%	678	0.90	659	5,409
three	8/22/03	366.2	79.5%	690	0.97	673	5,421
three	8/22/03	351.6	78.2%	679	0.92	661	5,438
three	8/22/03	342.9	77.1%	685	0.92	667	5,446
three	8/22/03	363.0	78.6%	677	0.93	658	5,464
three	8/21/03	407.5	82.5%	695	0.27	679	5,334

Table A.4. NO_x data for catalyst C4 (plate).

Chamber	Date	Inlet NO_x ppm (est)	NO_x reduc.	T before cat, F	NH_3/NO	Avg T catal, F	SV, hr^{-1}
four	3/26/03	312.0	92.1%	663	1.31	650	2154
four	3/27/03	324.4	94.5%	660	1.37	647	2,148
four	3/27/03	322.4	94.6%	661	1.32	648	2,158
four	3/27/03	307.7	94.3%	658	1.45	644	2,147
four	3/27/03	336.4	94.8%	659	1.26	647	2,154
four	3/27/03	326.4	94.8%	656	1.36	645	2,152
four	3/27/03	328.3	94.1%	663	1.46	654	2,984
four	3/27/03	325.0	87.0%	669	1.28	665	3,064
four	4/5/03	301.4	88.8%	685	1.27	676	6007
four	4/5/03	301.4	61.3%	489	1.26	456	6001
four	8/12/03	331.7	75.1%	617	1.19	605	2,541
four	8/13/03	318.9	64.0%	626	0.91	615	2,669
four	8/22/03	350.8	86.9%	686	0.97	673	3,196
four	8/22/03	364.3	87.4%	690	0.98	677	3,220
four	8/22/03	342.3	86.2%	691	1.02	677	3,224
four	8/22/03	366.7	86.3%	689	0.97	676	3,325
four	8/22/03	367.5	87.2%	690	0.95	677	3,421
four	8/22/03	352.7	84.9%	680	0.93	666	3,917
four	8/22/03	340.8	84.4%	686	0.93	671	4,012
four	8/22/03	364.4	84.9%	678	0.93	663	4,031
four	8/22/03	335.0	83.3%	676	0.92	663	4,059
four	8/11/03	334.5	79.8%	617	1.02	603	4,169
four	8/21/03	376.0	87.2%	693	1.32	679	4,170
four	8/21/03	371.7	86.7%	692	1.27	678	4,216
four	8/21/03	389.0	87.8%	701	1.04	685	4,235
four	8/21/03	381.3	87.4%	697	0.85	683	4,250
four	8/21/03	384.5	87.4%	695	0.94	680	4,250
four	8/21/03	373.4	86.5%	691	1.18	676	4,323
four	8/21/03	405.1	88.3%	696	0.53	681	4,308

Table A.5. NO_x data for catalyst C5 (monolith).

Chamber	Date	Inlet NO_x ppm (est)	NO_x reduc.	T before cat, F	NH_3/NO	Avg T catal, F	SV, hr^{-1}
five	3/26/03	330.9	88.3%	663	1.39	638	6988
five	3/27/03	320.0	90.4%	663	1.32	637	6,997
five	3/27/03	321.6	88.9%	660	1.25	635	7,026
five	3/27/03	303.5	89.2%	659	1.44	633	7,068
five	3/27/03	334.6	89.1%	658	1.29	635	7,016
five	3/27/03	326.9	88.5%	656	1.40	633	6,977
five	3/27/03	333.1	98.4%	663	1.36	641	7,021
five	3/27/03	328.7	79.7%	663	1.23	649	6,993
five	3/27/03	313.8	85.7%	668	1.31	656	7,047
five	4/5/03	301.4	83.2%	684	1.27	646	10772
five	4/5/03	301.4	67.2%	528	1.27	457	10924
five	8/12/03	331.7	72.4%	607	1.19	543	3,635
five	8/13/03	318.9	66.1%	608	0.92	547	4,564
five	8/16/03	349.1	68.0%	645	1.18	604	6,973
five	8/21/03	385.0	90.7%	695	0.94	665	9,742
five	8/21/03	402.9	90.7%	697	0.79	667	9,742
five	8/21/03	387.9	90.6%	698	1.06	669	9,743
five	8/21/03	380.6	90.7%	696	1.01	667	9,741
five	8/21/03	375.3	90.6%	694	1.23	663	9,740
five	8/21/03	371.9	90.3%	692	1.28	662	9,741
five	8/21/03	373.4	90.9%	691	1.15	660	9,743
five	8/22/03	365.9	89.6%	677	0.94	646	9,740
five	8/22/03	353.9	89.3%	680	0.93	649	9,738
five	8/22/03	333.7	88.3%	677	0.91	646	9,743
five	8/22/03	338.7	88.5%	686	0.94	654	9,741
five	8/22/03	367.2	89.6%	689	0.96	658	9,744
five	8/22/03	369.2	89.5%	689	0.95	658	9,742
five	8/22/03	340.7	89.3%	691	1.02	660	9,743
five	8/22/03	365.2	90.3%	691	0.98	660	9,739
five	8/22/03	350.3	89.4%	685	0.98	656	9,740
five	8/16/03	349.1	58.7%	608	3.75	544	2,593

Table A.6. NO_x data for catalyst C6 (monolith).

Chamber	Date	Inlet NO_x ppm (est)	NO_x reduc.	T before cat, F	NH_3/NO	Avg T catal, F	SV, hr^{-1}
six	3/26/03	324.0	81.6%	660	1.41	632	7198
six	3/27/03	313.1	79.9%	663	1.31	633	7,174
six	3/27/03	320.2	81.3%	663	1.34	632	7,191
six	3/27/03	309.7	79.2%	658	1.40	629	7,208
six	3/27/03	325.9	79.3%	655	1.35	628	7,213
six	3/27/03	334.3	81.5%	667	1.45	641	7,170
six	4/5/03	301.4	70.4%	684	1.27	649	10745
six	4/5/03	301.4	67.7%	554	1.28	494	10737
six	8/12/03	331.7	64.4%	603	1.22	555	2,219
six	8/13/03	318.9	58.2%	613	0.93	566	2,314
six	8/21/03	387.9	86.2%	695	0.94	673	9,619
six	8/21/03	400.9	86.2%	696	0.79	674	9,632
six	8/21/03	386.9	85.8%	697	1.04	675	9,606
six	8/21/03	379.9	85.9%	694	1.19	673	9,611
six	8/21/03	374.7	86.2%	693	1.30	671	9,615
six	8/21/03	372.1	86.0%	693	1.27	671	9,631
six	8/22/03	367.3	88.2%	676	0.92	655	9,614
six	8/22/03	355.0	87.1%	679	0.92	657	9,631
six	8/22/03	332.5	83.9%	679	0.92	657	9,660
six	8/22/03	336.5	85.7%	687	0.98	665	9,618
six	8/22/03	367.7	87.6%	689	0.97	668	9,623
six	8/22/03	370.9	88.3%	687	0.94	667	9,639
six	8/22/03	339.1	87.0%	691	1.03	670	9,630
six	8/22/03	366.2	88.9%	691	0.98	670	9,640
six	8/22/03	349.7	88.3%	685	0.98	664	9,603
six	8/22/03	357.7	80.6%	685	0.98	662	9,626
six	8/22/03	364.5	79.1%	691	0.98	669	9,634